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Addendum to: Implications of the measurements of B_s–$\overline{B_s}$ mixing on SUSY models

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This is an addendum to the previous publication, P. Ko and J.-h. Park, Phys. Rev. **D80**, 035019 (2009). The semileptonic charge asymmetry in B_s decays is discussed in the context of general MSSM with gluino-mediated flavor and CP violation in light of the recent measurements at the Tevatron.

In this addendum to Ref. [1], we discuss the semileptonic charge asymmetry in the B_s decays in general SUSY models with gluino-mediated flavor and CP violation, in light of the recent measurements of like-sign dimuon charge asymmetry by DØ Collaboration at the Tevatron. The model is described in Ref. [1], to which we refer for the details of the model and other phenomenological aspects related with B_s–$\overline{B_s}$ mixing, the branching ratio of and CP asymmetry in $B \to X_s\gamma$, $B_d \to \phi K_S$ and CP asymmetry in $B_s \to J/\psi\phi$.

One can define the semileptonic charge asymmetry in the decay of B_q mesons as

$$a^q_{\rm sl} \equiv \frac{\Gamma(\overline{B^0_q}(t) \to \mu^+ X) - \Gamma(B^0_q(t) \to \mu^- X)}{\Gamma(\overline{B^0_q}(t) \to \mu^+ X) + \Gamma(B^0_q(t) \to \mu^- X)}, \tag{1}$$

for $q = d, s$. In terms of the matrix elements of the effective Hamiltonian describing the damped oscillation between B^0_q and $\overline{B^0_q}$, the asymmetry $a^q_{\rm sl}$ is given by

$$a^q_{\rm sl} = {\rm Im}\frac{\Gamma^q_{12}}{M^q_{12}} = \frac{|\Gamma^q_{12}|}{|M^q_{12}|}\sin\phi_q, \tag{2}$$

where $\phi_q \equiv \arg(-M^q_{12}/\Gamma^q_{12})$. That is, this is another observable measuring CP violation in B_q–$\overline{B_q}$ mixing. We take the approximation, $\Gamma^q_{12} = \Gamma^{q,{\rm SM}}_{12}$, since the leading contribution comes from the absorptive part of the box diagrams for B_q–$\overline{B_q}$ mixing and there is no new common final state into which both B_q and $\overline{B_q}$ can decay in our scenario. The size of M^q_{12} is fixed by the ΔM_q data up to hadronic uncertainties. Then, $a^q_{\rm sl}$ can be regarded as a sine function of ϕ_q, multiplied by the factor $|\Gamma^q_{12}|/|M^q_{12}|$. This curve is traversed as one allows for arbitrary supersymmetric contributions to M^q_{12} obeying the ΔM_q constraint. Combining the SM predictions [2],

$$\begin{aligned} |\Gamma^{s,{\rm SM}}_{12}|/|M^{s,{\rm SM}}_{12}| &= (49.7 \pm 9.4) \times 10^{-4}, \\ \phi^{\rm SM}_s &= (4.2 \pm 1.4) \times 10^{-3}, \end{aligned} \tag{3}$$

one finds the vanishingly small asymmetry $a^{s,{\rm SM}}_{\rm sl} \sim 2 \times 10^{-5}$.

Recently, the DØ collaboration reported a measurement of like-sign dimuon charge asymmetry [3]. They interpreted the result as coming from the mixing of neutral B mesons and have found an evidence for an anomaly in the asymmetry,

$$A^b_{\rm sl} \equiv \frac{N^{++}_b - N^{--}_b}{N^{++}_b + N^{--}_b}, \tag{4}$$

where N^{++}_b and N^{--}_b are the number of events where decays of two b hadrons yield two positive and two negative muons, respectively. Their result shows a discrepancy of 3.2σ from the SM expectation. This asymmetry consists of $a^d_{\rm sl}$ coming from B_d decays as well as $a^s_{\rm sl}$ from B_s. One can extract the asymmetry relevant to the B_s meson using the measured value of $a^d_{\rm sl}$ and the result by DØ is

$$a^s_{\rm sl} = -0.0146 \pm 0.0075. \tag{5}$$

This is 1.9σ away from the SM prediction. We shall use this data in the following discussion.

This DØ result has drawn interest in new physics explanations [4–8]. (For earlier works, see e.g. Refs. [9–11].) Some of the works consider extra contributions to Γ^q_{12} since the dimuon charge asymmetry depends on it as well as on M^q_{12} [5, 6]. This approach also has a possibility of altering $|\Delta\Gamma_s|$ even though its current experimental value is in agreement with the SM one, $2\,|\Gamma^{s,{\rm SM}}_{12}\cos\phi^{\rm SM}_s|$ [2, 12, 13]. As we said, Γ^q_{12} is fixed in the present work and we are left only with the option of modifying M^s_{12}. Therefore, $|\Delta\Gamma_s|$ shall become smaller than its SM prediction as $|\phi_s|$ grows up to $\mathcal{O}(1)$.

We perform the numerical analysis in the same way as in the main article [1]. The crucial ingredient for evaluating $a^s_{\rm sl}$ is the range of ϕ_s to be used. Following the latest reports from DØ [3] and CDF [14], there have been a couple of attempts to make a global fit of B_s–$\overline{B_s}$ mixing parameters including ϕ_s [4, 6]. However, the official combination is not available yet. Partly because of this reason and partly for the sake of coherent presentation, we keep using the range used in Refs. [1, 15],

$$\phi_s \in [-1.10, -0.36] \cup [-2.77, -2.07]. \tag{6}$$

As a matter of fact, this range is not very different from the 2σ interval found in Ref. [6]. As for $\Gamma^{s,{\rm SM}}_{12}/M^{s,{\rm SM}}_{12}$, we take its central value from Eqs. (3). Considering the error in this ratio could add 20% more of uncertainty to the thickness of the $a^s_{\rm sl}$ band in the following figures.

We show $a^s_{\rm sl}$ as a function of ϕ_s for $\tan\beta = 3$ in Figs. 1. The four plots are for the LL, the RR, the $LL = RR$, and

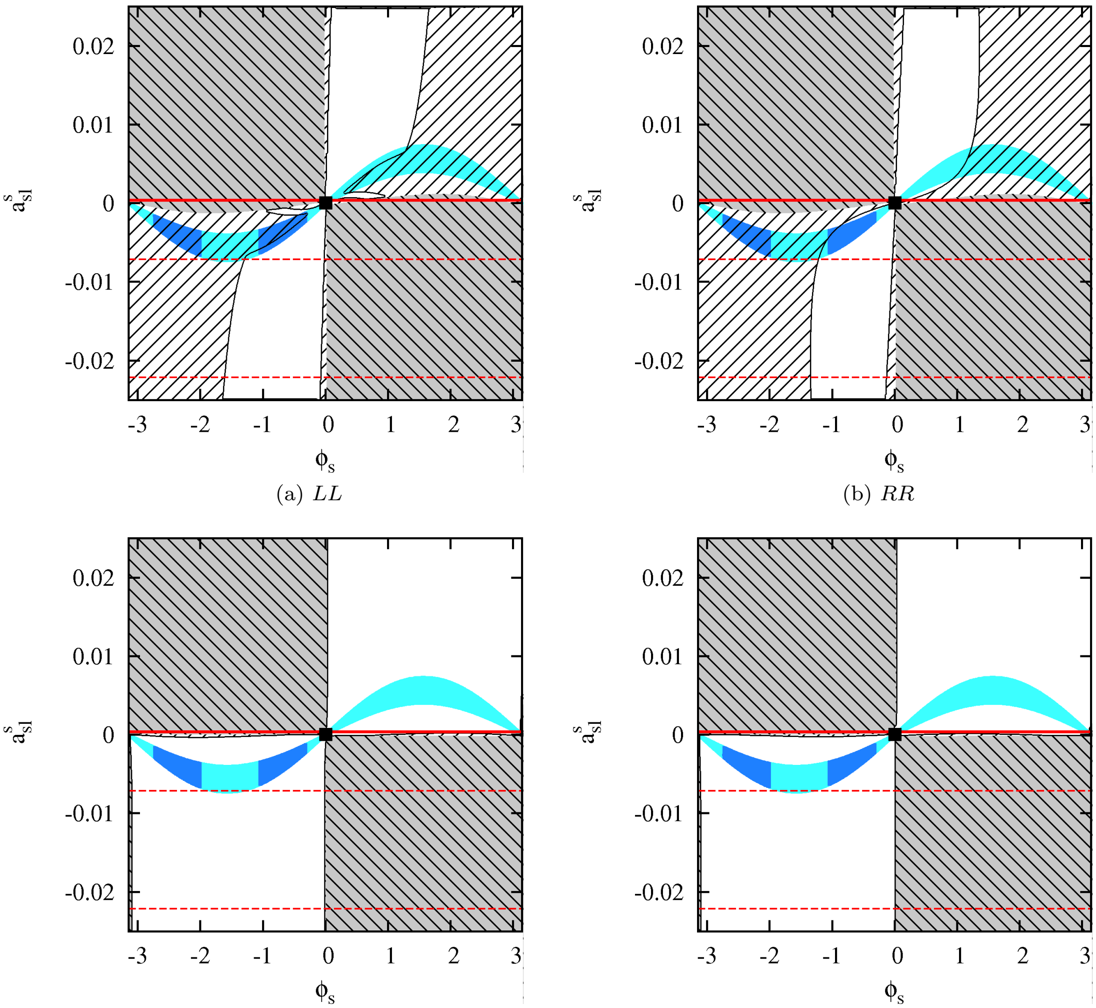
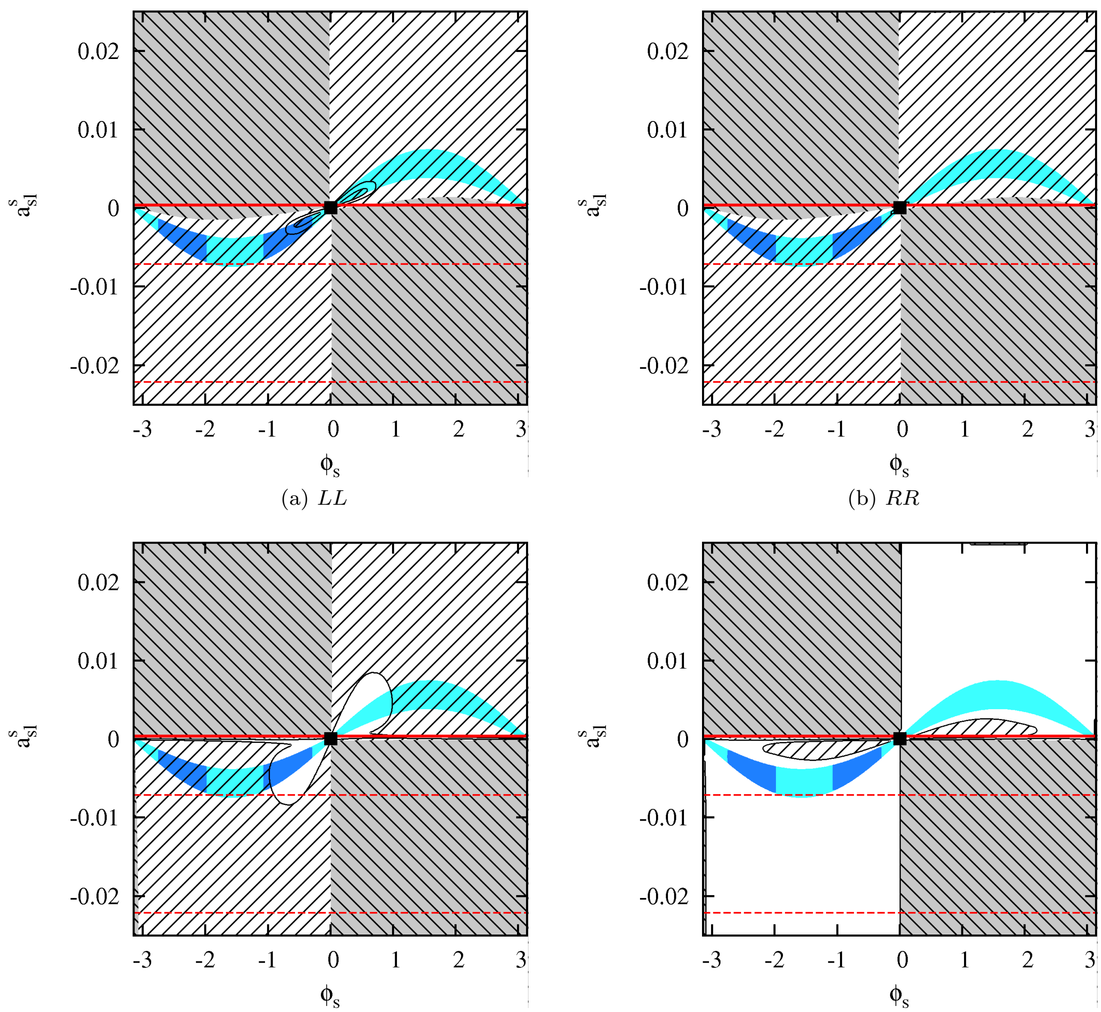


FIG. 1. Plots of $a^s_{\rm sl}$ as a function of ϕ_s for the four different cases with tan$\beta = 3$. The hatched gray region leads to the lightest squark mass < 100 GeV. The hatched region is excluded by the $B \to X_s\gamma$ constraint. The light gray region (cyan online) is allowed by ΔM_s. The dark gray region (blue online) is allowed both by ΔM_s and ϕ_s. The black square is the SM point. The dashed and solid lines (both red online) mark the 1σ and 2σ ranges of $a^s_{\rm sl}$, respectively.

the $LL = -RR$ cases, respectively. One can immediately notice the aforementioned sinusoidal dependence of $a^s_{\rm sl}$ on ϕ_s, coming from Eq. (2) and the ΔM_s constraint. This feature is not only true of all the cases shown here but also of any new physics model that does not affect Γ^s_{12}. The nonzero thickness of the band arises from the uncertainty in ΔM_s. The difference between $a^s_{\rm sl}$ and its central value is at least about 1.0σ. This discrepancy becomes worse but only slightly after ϕ_s is restricted inside its preferred ranges (colored in blue). If one incorporates the $B \to X_s\gamma$ constraint, substantial part of the blue regions is excluded, in particular in the upper two cases with one insertion. Even then, however, the lowest possible value of $a^s_{\rm sl} \simeq -0.006$ within the blue region does not change. In the lower two cases with two insertions, $B \to X_s\gamma$ does not play an important role since the supersymmetric effect on B_s–$\overline{B_s}$ mixing is enhanced.

Plots for tan$\beta = 10$ are displayed in Figs. 2. The model-independent characteristics dictated by Eq. (2) remain exactly the same as in the previous set of figures. The only difference is the stronger $B \to X_s\gamma$ constraint due to higher tanβ. Here, it excludes more part of the blue regions. Again, this is particularly true of the upper two cases in which $a^s_{\rm sl}$ is restricted closer to its SM value. In Fig. 2(a), ΔM_s, ϕ_s, and $B \to X_s\gamma$, together allow $a^s_{\rm sl}$ to be as low as -0.003. In Fig. 2(b), there is no solution satisfying all the three constraints. One could get $a^s_{\rm sl} \simeq -0.0006$ if ϕ_s were not limited. In the lower two cases, the lowest $a^s_{\rm sl}$, compatible with ΔM_s and ϕ_s, is almost the same as in Figs. 1.

We summarize. We have examined how $a^s_{\rm sl}$ is influenced by the LL and/or RR mass insertions. For tan$\beta = 3$, one can reduce the discrepancy between $a^s_{\rm sl}$ and its SM expectation from 1.9σ down to 1.0σ in each



(a) LL

(b) RR

(c) $LL = RR$

(d) $LL = -RR$

FIG. 2. Plots with $\tan\beta = 10$. The meaning of each region is the same as in Figs. 1.

of the LL, RR, $LL = RR$, and $LL = -RR$ cases, obeying the ΔM_s, $B \to X_s\gamma$, and ϕ_s constraints. This amounts to reduction of the $A^b_{\rm sl}$ tension from 3.2σ down to 2.2σ if one assumes no new physics in the $b \to d$ transition. For $\tan\beta = 10$, it becomes difficult for the LL and RR cases whereas the $LL = RR$ and $LL = -RR$ cases are less limited by $B \to X_s\gamma$.

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NOTE ADDED

While we were waiting for the approval for submission, a paper by J. K. Parry appeared on the e-print archive that employs a related model [8]. However, the flavor structure of the squark mass matrix therein is different from any of those here. As far as squarks are concerned, he considers only one case where $(\delta^d_{23})_{RR}$ is a variable parameter and $(\delta^d_{23})_{LL}$ is fixed to a value that comes from renormalization group running. This way of parameter scan is not covered in this work. He does not display the $B \to X_s\gamma$ constraint on his plots, but it may not be very restrictive in his case depending on μ and $\tan\beta$. (See e.g. Fig. 4 in Ref. [16].)

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